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NEUTRON CHOPPER DEVELOPMENT AT LANSCE

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ABSTRACT

Progress is reported on neutron chopper systems for the Los Alamos Neutron Scattering Center pulsed spallation neutron source. This includes the development of a 600+ Hz active magnetic bearing neutron chopper and a high speed control system designed to operate with the Proton Storage Ring to phase the chopper to the neutron source.

I. INTRODUCTION:

Choppers for inelastic epithermal neutron scattering experiments at the Los Alamos Neutron Scattering Center (LANSCE)[1] must meet three criteria. First, they must operate continuously with minimal maintenance during the typically six months run cycle of the LANSCE facility. Second, they must provide the maximum transmission in a short pulse of neutrons of the order of 2 μsec FWHM to match the neutron source resolution, a feature which requires as high a rotation speed as possible.[2] Third, the chopper must be timed with the neutron source to transmit neutrons of only one time-of-flight (energy). This is difficult because the LANSCE pulsed neutron source is synchronized to the variations of the power line frequency and phase within time windows set by the limits of accelerator operations.

Previously, Los Alamos had reported[3,4] on a successful test of a control system for phasing neutron choppers to the proton bursts from the Los Alamos Meson Physics Facility (LAMPF) accelerator on the WNR facility target. This involved a partial PID control of a low speed (240 Hz)

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*Engineering consultants to the Los Alamos National Laboratory mechanical bearing chopper as well as triggering the LAMPF accelerator within an allowed 128 μsec window from a magnetic pickup on the chopper. This system would not allow more than one chopper to operate at the same time.

This paper is a report on progress on chopper systems at Los Alamos in the past two years. Los Alamos has acquired a high speed (600+ Hz) active magnetic bearing chopper. It has also developed a high speed control system which will operate with the Proton Storage Ring[5] and which will permit several choppers to be phased to the source simultaneously.

II. ACTIVE MAGNETIC BEARING NEUTRON CHOPPER:

To meet the first two criteria, a mechanical rotating chopper which uses active magnetic bearings (AMB) has been designed, manufactured by S2M Corporation in Vernon, France, and delivered to Los Alamos.

There were many reasons to choose magnetic bearing technology over more conventional mechanical bearing technology. The no-wear feature of magnetic bearings, due to the absence of metal-to-metal contact, will allow the unit to operate continuously for long periods of time without the need to shut down for bearing replacement maintenance. Because there is no need for lubrication, which can introduce varying frictional loads and limit the allowable surface velocity, the rotating member can be large and still operate at very high speeds (i.e., at 600 Hz and above). Because such a system is stiff, the operating speeds can still be below the critical frequencies of the mechanical system (870 Hz in the present case), greatly simplifying the acceleration and deceleration. By eliminating the variable frictional load of mechanical lubricated bearings and the flexibility of the mechanical system, the control problem is reduced to that of following the variations in neutron pulse timing primarily caused by power line variations.

There are many additional advantages for a magnetic bearing system. The rotor is self-balancing, turning around its principal axis of inertia rather than around the axis of the bearings. This results in vibration free, silent operation because there is no stress on the bearings. There is a very low heating of the bearings, a very low power consumption, and a very wide temperature operating range. The bearing stiffness is adjustable electronically, providing great precision in setting the rotor equilibrium position. The suspension damping is also adjustable, which enables passing the rotor critical speeds without difficulty. (However, as mentioned earlier, in the initial design the first critical speed (870 Hz) is above the design operating speed (600 Hz).) It is also possible to permanently monitor the machine during operation because the data from the AMB electronic position sensors provide constant information on rotation characteristics. The system provides all the information required for in-situ balancing. There is also electronic information to initiate an automatic shutdown in the case of excess machine vibration or malfunction.

Figure 1 is a schematic drawing of the active magnetic bearing neutron chopper which was acquired from S2M Corporation in Vernon, France. These systems now can also be manufactured by Inland Motor Corporation in the U.S., which has licensed the technology from S2M. The neutron chopper consists of a vertically oriented shaft supported by an axial thrust bearing and two radial bearings. The 3 KW, 3 phase induction motor squirrel cage rotor is an integral part of the vertical shaft and provides the rotational driving force. The neutron chopping Fermi slit package is contained in a replaceable aluminum drum which forms a part of the vertical shaft. The radial bearings are located near the top of the shaft and at the bottom below the slit package. The entire shaft assembly runs in a vacuum, thus reducing the windage and power consumption, and is compatible with operation in an evacuated beam line. In case of power failure of the mains, battery back-up is provided to maintain the magnetic bearing operation until the unit is decelerated and comes to a stop. There are also mechanical back up bearings.

III. CONTROL SYSTEM OVERVIEW:

The major system elements and associated controls are illustrated in Fig. 2. Proton macropulses are generated in the LAMPF linear accelerator with the 2nd harmonic (120 Hz) of the incoming power grid. These proton pulses are typically 750 usec in length with the leading edge occurring 200 usec after the zero voltage crossover of the phase of the grid power.

Every 10th proton macropulse is injected into the recently constructed Proton Storage Ring (PSR) at a pulse repetition rate of 12 Hz. The macropulse is chopped into segments 0.27 usec long separated by 0.09 usec, each segment of which is fed into an electromagnetic bucket for protons in the PSR which makes a revolution about the ring every 0.36 usec. When the macropulse injection is completed, PSR specifications require that the stored proton bunch of 0.27 usec length be extracted within 200 usec onto the high Z spallation target to produce neutrons. The neutrons from the target are slowed down in hydrogenous moderators to the energies required for neutron scattering research. This produces a neutron burst with FWHM pulse width of approximately 2 usec/ $\sqrt{E(eV)}$, where E is the neutron energy, for epithermal (E > 0.1 eV) neutrons. The neutrons travel down the beam line toward the chopper, whose purpose is to select a neutron time of flight, i.e., monochromate the beam. The chopper has a aluminum boron fiber composite Fermi slit package optimized[2] for intensity and resolution.

The primary specifications of the chopper control system arise from the need to achieve the best energy resolution by controlling the time-of-flight to much better than the neutron pulse width. The desired neutron time slice is a function of the chopper angular velocity; for this system, the control provides a selectable angular velocity ranging from 120 Hz to 600 Hz in steps of 60 Hz. The control system divides the time taken for a complete chopper revolution in 0.1 μsec increments. The control system is capable of allowing the selection of any desired time-of-flight, with a 0.1 μsec granularity. In practice, the system can be no more precise than the PSR circulation time of 0.36 μsec. The control system design specification has been set at ± 0.3 μsec root sum square (RSS) control accuracy in the time-of-flight.

Bolie et. al.[3,4] described an experimental system which phased a 240 Hz mechanical bearing chopper to LAMPF. The results were in general agreement with theoretical expectations; however, they fell far short of the required accuracy. A major limitation on the accuracy was shown to be the random variability of the grid power which, via the LAMPF synchronization with the grid, produced a random variability in the proton macropulse repetition rate. Bolie et. al. showed that the grid power variability was dominated by two terms. The first is a high frequency crossover to crossover jitter of ± 8 μsec; the second is a slow periodic variability of ± 8 μsec at a rate of approximately 1.2 radians/second. This level of variability was far beyond the tracking capability of the control system. Of even greater significance was the random nature of the variability which eliminated the opportunity to predict the arrival time of the next pulse based on data from the previous pulse. To circumvent this problem, a feedback signal was taken from a magnetic stud pickup on the chopper, the function of which was to modify the LAMPF trigger point to be compatible with the chopper instantaneous position. This approach substantially enhanced system accuracy but was still below the accuracy objective. Furthermore, it limited the facility to the use of a single chopper.

Further analysis conducted on the chopper control dynamics showed that a system bandwidth in excess of 1200 radians/sec would be required to track the jitter component on a pulse-by-pulse basis and that this bandpass requirement would require a motor drive power in excess of 10 kilowatts. In contrast, tracking the slow periodic variability requires a control system bandwith of 12 radians/sec and a motor drive power on the order of 1 kilowatt.

In view of these widely disparate requirements, we decided to reconfigure the system to treat the two variability components separately. The reconfigured system eliminates the jitter component through electronic filtering techniques and uses a 3 kilowatt motor to track the low frequency periodic variability. The revised configuration is illustrated schematically in Fig. 3. In this configuration the control system is a combination forward loop control of LAMPF and PSR coupled with a closed loop feedback control of chopper speed and phase.

The control system takes grid power zero crossings as its input. This signal is passed through a loosely coupled phase lock loop which has a zero gain bandwidth of 12 radians/sec. The output signal is 120 Hz in phase with the input signal for all input frequency perturbations up to 1.2 radians/sec and progressively rejects increasing levels of high frequency input perturbations. This produces a 20:1 attenuation level which reduces the 16 µsec jitter to 0.8 µsec. Attenuation levels beyond this magnitude have no benefit since LAMPF has an inherent jitter of 1 µsec. The output is a 120 Hz carrier frequency that is essentially jitter free and is overmodulated with a low frequency component corresponding to the grid power behavior. This signal is used to trigger LAMPF in a predictable manner. In practice, this trigger signal is well within the ± 64 µsec range of the zero crossings set by LAMPF operations requirements.

The time interval between triggering LAMPF and total capture of the proton macropulse by the PSR is a constant of 950 µsec for a 750 µsec wide macropulse. PSR specifications limit the storage of the macropulse for a maximum of 200 µsec after capture. To take account of these characteristics the output of the jitter filter is passed through a time delay, the value of which corresponds to the LAMPF/PSR delay plus half the allowable PSR storage time, and then passed on to a programmable frequency multiplier.

This multiplier takes the form of an additional loosely coupled phase locked loop, again with a bandwidth of 12 radians/sec. Thus it provides a further 20:1 attenuation on grid jitter reducing its level under worst case conditions to less than 0.04 µsec. The output of the multiplier is in phase with its input signal, synchronized through the delay action to be at the mid-point of the PSR holding time, and its frequency is that at which the chopper is required to run. By taking a function of the multiplier output as the PSR trigger, the PSR proton release is synchronized to the motor control system.

Control of the neutron time-of-flight is achieved by placing a programmable time delay between the motor control system and the multiplier output. The chopper assembly incorporates a stud type position reference which passes a magnetic monopole speed sensor when the slit package is in line with the neutron source. The monopole produces a fast leading edge pulse under line up conditions. The motor control system is a tightly coupled phase lock loop, having a bandwidth of 87 radians/sec, and acts to modulate the motor excitation frequency such as to keep the stud feedback signal precisely in phase with the delayed frequency multiplier output. By placing the time-of-flight delay in the forward loop as opposed to the feedback path, time-of-flight can be directly dialed. More importantly, time-of-flight accuracy is not affected either by selected chopper speed or low frequency perturbations of grid frequency.

Provisions are incorporated in the chopper assembly for a laser position feedback signal to supplement the magnetic monopole system. This provides a higher accuracy position feedback, if required.

This control architecture allows the use of multiple choppers through replication of the frequency multiplier and motor control system in as many installations as required. Synchronization of additional choppers is achieved by driving each additional chopper from the PSR trigger signal.

IV. CURRENT STATUS:

S2M supplied the active magnetic bearing chopper system to Los Alamos along with a dummy rotor and control cabinet in February, 1985. Initial commissioning tests began in May and the early test results were encouraging. The chopper operated at all power line harmonic speeds from 60 Hz to 600 Hz with no observable limitations due to unexpected vibration criticals. Velocity command changes from minimum to maximum speeds are executed in 120 seconds.

So far there have been only four days of testing of the control system with the S2M chopper. The jitter filter, LAMPF trigger, frequency multiplier, PSR trigger, and delay network are validated. Phase control of the chopper encountered a stability problem due to an additional lag associated with the motor drive system. This lag limited the motor drive bandwidth to 11.8 radians/sec and produced a cyclic time-of-flight wander of ± 10 usec. Subsequent analysis of the revised dynamics have shown good theoretical agreement with the test results. Modifications are in process to the motor drive system to provide the required bandwidth and stability. Testing is expected to resume in July with the system becoming available for operation concurrent with PSR availability during the last quarter of 1985.

Testing of the system with neutrons from the PSR is scheduled to begin in October, 1985. Based on the success of these tests, Los Alamos will proceed with the design and development of a chopper spectrometer for 1986 construction.

V. ACKNOWLEDGEMENTS

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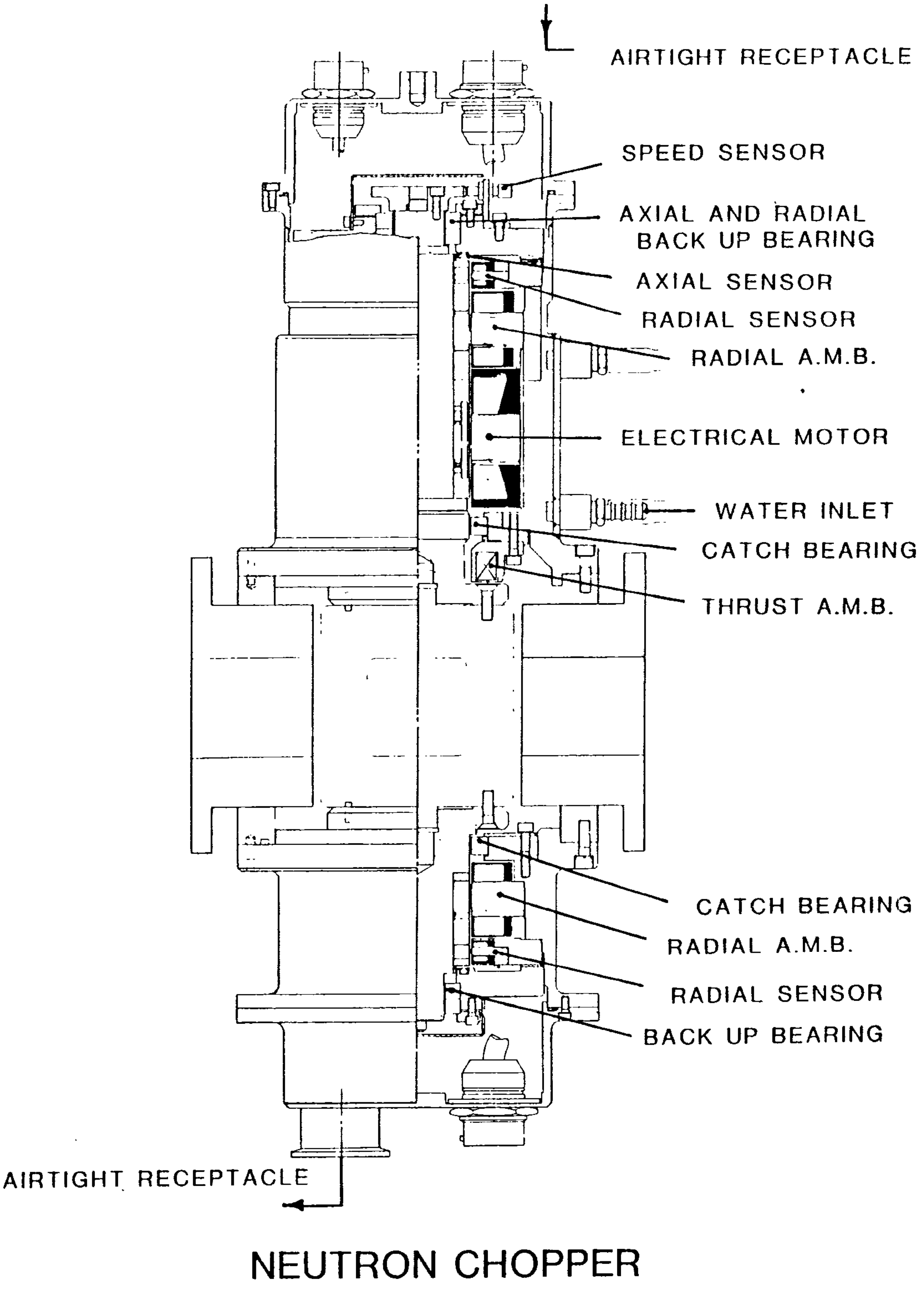

Fig. 1 Schematic diagram of the active magnetic bearing neutron chopper supplied by S2M Corporation.

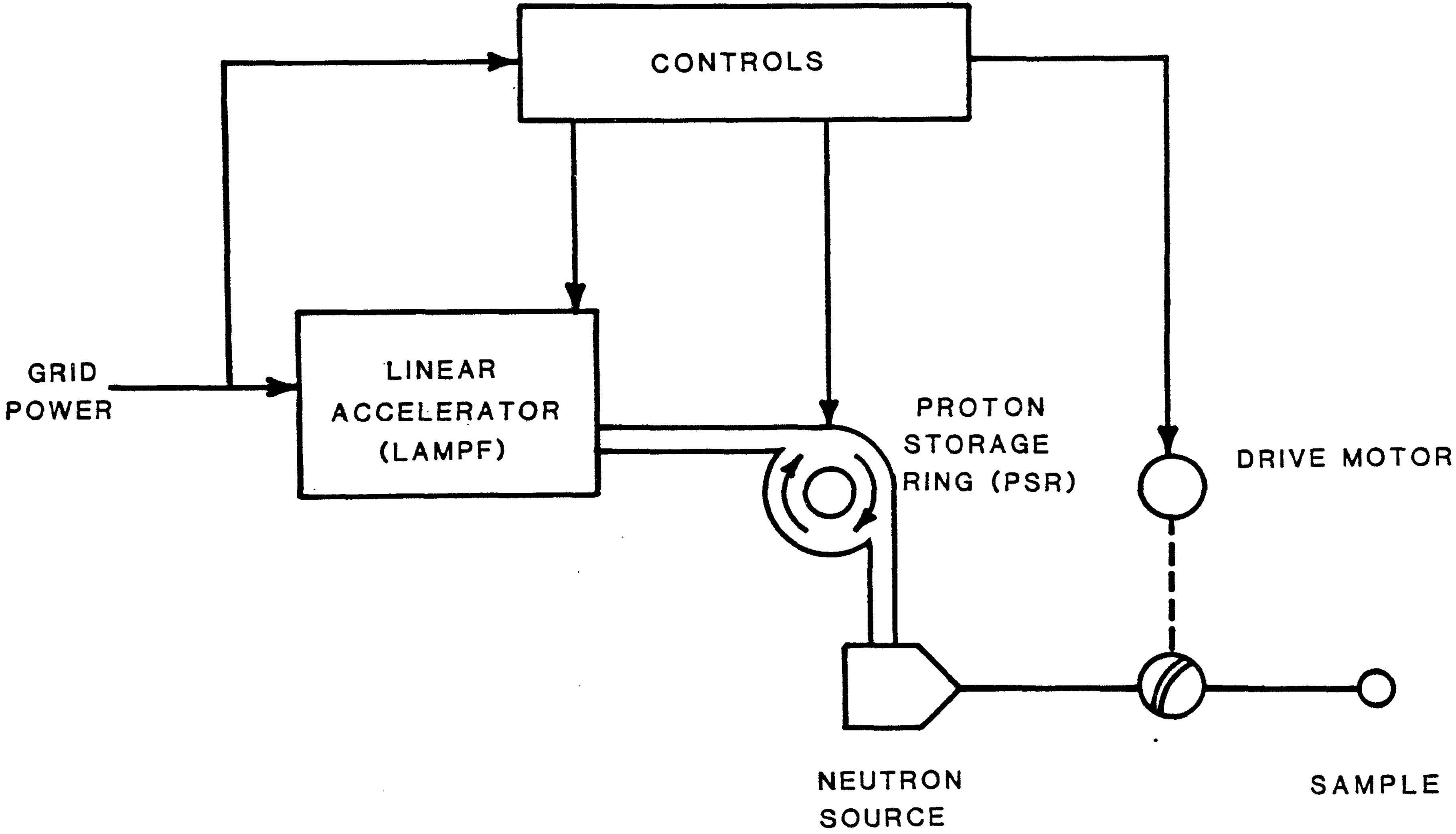

Fig. 2 General arrangement of acclerator, chopper, and controls.

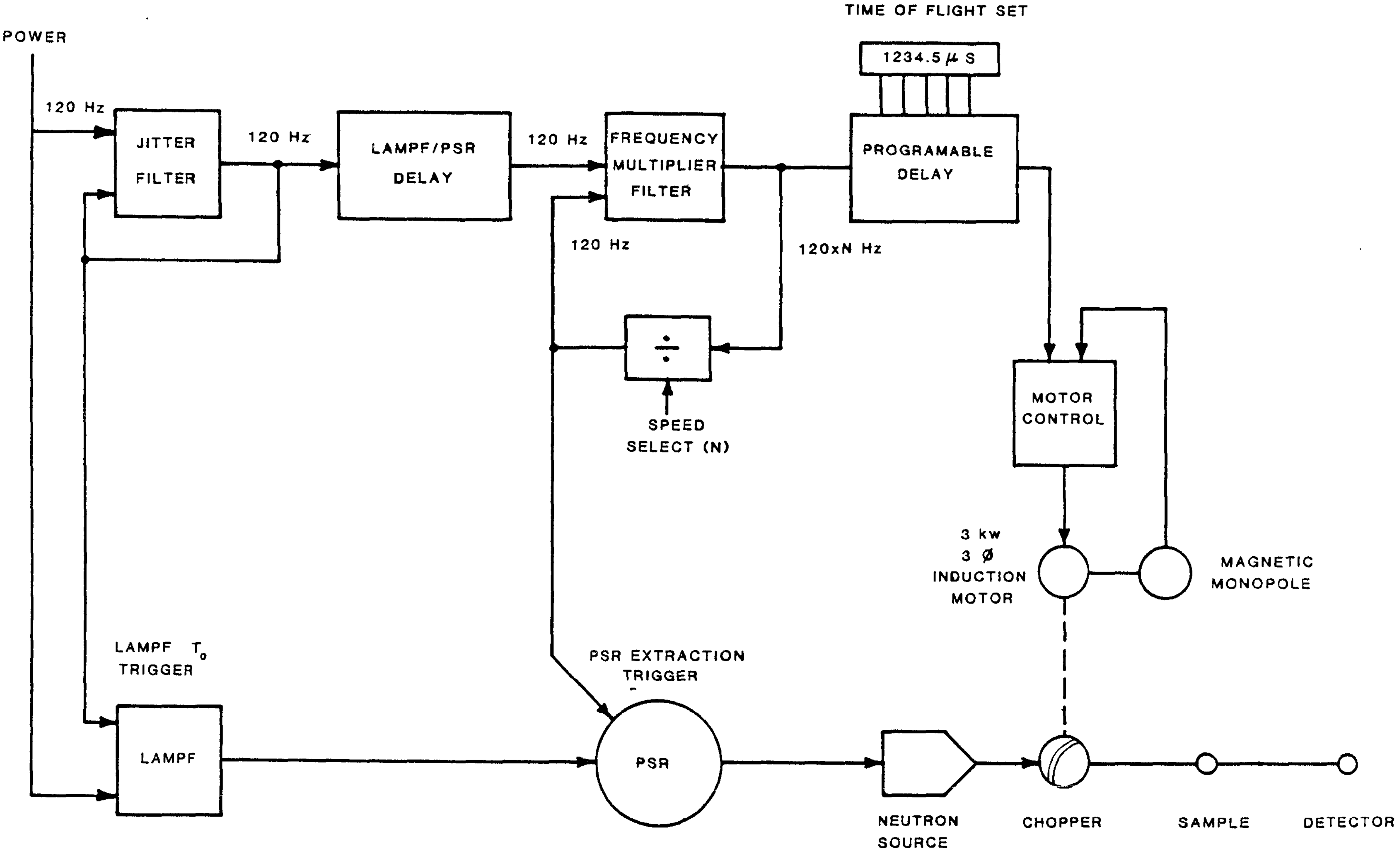

Fig. 3 Reconfigured chopper control system architecture.